EPA

OMS Advisory Circular

SUBJECT: Determination and Use of Alternative Dynamometer Power Absorber Settings

I. Purpose

This advisory circular (A/C) refines and clarifies the procedures to be used by vehicle manufacturers in establishing alternative dynamometer power absorber settings. The previous A/C, No. 55B, was published in 1978. Since that time both the manufacturers and EPA have gained considerable experience in the determination of alternative dynamometer power absorber settings. Consequently, EPA finds it appropriate to grant the manufacturers increased flexibility in making such determinations. Also, to avoid potential misunderstandings, the manufacturers' responsibilities when using such alternative dynamometer settings are more clearly stated below.

II. Background

A. When a vehicle is tested for emissions and fuel economy on a chassis dynamometer, aerodynamic drag, friction and tire losses associated with road operation must be simulated. EPA has established empirical formulas relating such factors as frontal area, vehicle shape, weight and tire construction to dynamometer adjustment. (These formulas are found in 40 CFR 86.129.) However, manufacturers may, subject to the provisions of this advisory circular, establish vehicle specific alternative dynamometer power absorber settings. Currently, almost all vehicles certified by EPA have been tested using such alternative dynamometer settings.

B. An alternative dynamometer power absorber setting is determined in two stages. First, actual on-road operation must be characterized and, second, these on-road characterizations are simulated on the dynamometer. EPA has previously established test procedures for both steps; these have been republished, with minor changes, as attachments to this advisory circular.

C. The use of alternative dynamometer power absorber settings is optional. A manufacturer electing to use alternative dynamometer settings is responsible for seeing that the road force characterization and dynamometer settings are accurate for the vehicles which will be produced. EPA may test, or require the manufacturer to test, representative production vehicles to verify the appropriateness of the manufacturer's specification. In cases where significant discrepancies are detected, retesting for emission certification and recalculation of fuel economy values may be required. EPA considers the road force characterization and dynamometer settings to be vehicle specifications similar to curb weight. Certificates and fuel economy ratings are issued for vehicles which do, in fact, comply with the specifications.

III. Applicability

This advisory circular is effective beginning with the 1988 model year.

IV. Alternative Dynamometer Power Absorber Settings

A. Road Force Definition

1. A dynamometer power absorber is used to simulate conditions of actual on-road operation. The dynamometer power absorber is adjusted so that the total "force" experienced by the vehicle is the same as on the road. EPA currently uses water brake dynamometers with a fixed force versus speed relationship characteristic of aerodynamic drag. A 50 mile/hour speed is used as the adjustment point. (Manufacturers may use other types of dynamometers; acceptable correlation with EPA's laboratory is the manufacturer's responsibility.)

2. Because it cannot be measured directly, EPA has adopted the coastdown method to characterize road force. During a coastdown test the vehicle is allowed to decelerate with the transmission in neutral while its speed is periodically measured. Using Newton's Law (F = MA), force, mass and deceleration can all be related; a 55 to 45 mile/hour coastdown time is a convenient way to express deceleration and, indirectly, road force.

3. For a vehicle type with a given road force, the 55 to 45 mph coastdown time is a function of vehicle mass or, on the dynamometer, flywheel inertia. Appropriate corrections must be made for changes in weight or flywheel inertia.

B. Application/Test Procedures

1. A manufacturer must request, in writing, as a part of the application for certification, the use of alternative dynamometer power absorber settings. The request is made by submitting a list of the vehicles to be covered, road force specifications, dynamometer power absorber settings, a description of the test procedures used and other appropriate information as determined by the manufacturer. (For example, a manufacturer may have information to support use of a different temperature correction factor than used by EPA, Attachment I equation 14. Such a correction factor should be mentioned in the application.) The manufacturer must include a 55 to 45 mile/hour coastdown time even if the coastdown method is not used to characterize on-road operation; such a coastdown time may be calculated from appropriate data. A sample submission is included as Attachment IV; the manufacturer may use any logical format to present the required information.

2. The manufacturer may, within the constraints of good engineering practice, use any test procedure to characterize road force and determine proper dynamometer power absorber settings. In the past EPA formally approved the test procedures and methods (other than the EPA Recommended Practice) used to generate such alternative dynamometer settings. However, with years of experience by both EPA and industry, and with such techniques as wind tunnel and tire testing widely available, formal approval is no longer necessary and may be overly restrictive. Therefore, EPA will allow the manufacturer to select its own test procedures and calculation methods, such procedures and methods must be described in the application for certification. As an overall check, EPA will continue to test vehicles using the Recommended Practice Procedure. If such testing demonstrates that a manufacturer's procedures and methods are not accurate, EPA will refuse to accept additional test results until the deficiencies are corrected. Correction of previously submitted data will also be required where appropriate.

3. EPA recognizes that new testing and calculation procedures may be used. Wind tunnels, precision electric dynamometers, tire testing, component bench testing, etc., are tools and techniques that can be used to characterize changes in a vehicle's road load. EPA believes that ability to use such techniques will allow the manufacturer to reduce costs and to, hopefully, increase accuracy.

C. Vehicle Populations

To qualify for alternative dynamometer settings, vehicles must be grouped into populations which are expected to have similar road forces at 50 mph. For purposes of this grouping, the 55 to 45 mph coastdown time (adjusted for changes in vehicle mass) shall be considered the measure of road force. The manufacturer shall consider such items as carline, body style, transmission type, tire construction, tire rolling resistance, etc., in segmenting vehicle populations. Differences in tire size, manufacturer and other tire factors do not necessarily require separate vehicle populations; tires which have significant differences in rolling resistance will require separate populations. At the manufacturer's option, vehicles with lower road force (longer mass-corrected coastdown times) can be included in a population to be represented by a vehicle with higher road force. The groupings shall be made in such a manner that any production vehicle in the group shall, if confirmatory tested, meet the criteria set forth below at VI. If desired, the manufacturer may subdivide populations by equivalent test weight (ETW) classes.

D. Road Force Determination

1. For each population, a representative road force (55 to 45 mph coastdown time) must be established. The road force so established must be for a representative vehicle in the heaviest equivalent test weight (ETW) in the population. (This does not require testing the heaviest vehicle; the specification may be derived from test results on a lighter vehicle with correction for increased rolling resistance.) Options which will increase aerodynamic drag or driveline friction and which have a projected installation rate of over 33 percent on any carline in the population must also be reflected in the road force specification. In predicting installation rates, the manufacturer must consider actual installation rates in the past and other relevant factors to make an accurate forecast for the full model year.

2. Some vehicles have driver controlled equipment which may significantly affect road force. These vehicles should be tested and have a road force specification under conditions of normal or average operation. EPA has determined that convertibles, sun roofs and removable top vehicles are normally operated in a closed configuration; vehicles with manually engaged four-wheel drive are normally driven in two-wheel drive mode; windshield wipers are normally off. The manufacturer should make similar determinations for other such equipment.

E. Dynamometer Power Absorber Setting

1. The appropriate dynamometer adjustment simulates the road force encountered by the vehicle during actual operation. Within a given vehicle population (having similar road force characteristics) several dynamometer adjustments may be necessary. For example, a front-wheel drive vehicle population may include vehicles with vastly different drive axle weights. If the dynamometer setting is developed using a 2875 lb. ETW vehicle with optional diesel engine, automatic transmission and other optional equipment, a significant amount of the total power on the dynamometer is absorbed by the tires. A similar vehicle in the 2500 lb. ETW class with correspondingly less drive axle weight might be underloaded on the dynamometer if tested at the same setting.

2. The manufacturer must take steps to ensure that the dynamometer settings are appropriate for all members of the population. Additional segregation of a population may be necessary to assure that production vehicles shall, if tested, meet the criteria set forth below. The manufacturer may use any appropriate procedure in establishing the correct settings. At the manufacturer's option, the manufacturer may include vehicles which would qualify for lower dynamometer settings in a group with vehicles requiring higher settings.

3. Some vehicles must be tested with a dynamometer setting increased 10 percent (up to an additional 1.4 hp) to simulate the engine power consumed by an air conditioner. (See Advisory Circular No. 53.) The manufacturer must include this increased setting in its application, along with a matching dynamometer coastdown time, if testing with increased settings will be required.

F. Updating Specification, New Vehicles

A manufacturer electing to use alternative dynamometer settings has the obligation to update its application to adequately describe the vehicles which are to be produced. When an entirely new vehicle is to be introduced, the road force and dynamometer setting specification must generally be developed on a vehicle built of prototype parts or derived from data from various sources. Under such circumstances, a manufacturer should verify the specifications by testing actual production vehicles as soon as possible. This process may also be appropriate when extensive changes have been made to an existing vehicle.

V. Confirmations

A. General

1. A manufacturer electing to use alternative dynamometer power absorber settings is responsible for the accuracy of the road force and dynamometer setting specifications. Three techniques will be used to confirm vehicle performance and dynamometer adjustment:

- Road confirmations on production vehicles. This is to ensure that the road time reported by the manufacturer is representative of production. (Occasionally, confirmations on coastdown test vehicles may also be conducted.)
- Dynamometer power absorber confirmations on production and test vehicles.
- Quick-checks (comparison of dynamometer coastdown times with the vehicle specification) on all test vehicles. This is to ensure that the test vehicles are representative of the coastdown time and dynamometer setting reported by the manufacturer.

B. Road Confirmations

EPA may test, or require the manufacturer to test, production vehicles to verify road force specifications. EPA may also require a manufacturer to supply appropriate vehicles for EPA testing. Such testing may be at the manufacturer's test facility or at a facility leased by EPA at EPA's option. Test vehicles should have accumulated from 3,000 to 10,000 miles of service. Tires shall have 50 percent of the usable tread remaining, usable tread being the original tread, tread depth in excess of 2/32 of an inch. EPA will test using the recommended practice procedures, Attachment I.

C. Power Absorber Confirmation

As with road confirmations, EPA may determine, or require the manufacturer to determine, the appropriate power absorber setting for any test vehicle or category of production vehicles. EPA may require the manufacturer to supply vehicles for this purpose. The reference procedure is found in Attachment II.

D. Quick-Check Confirmations

1. After every highway fuel economy test on an emission or fuel economy vehicle, the manufacturer must perform a dynamometer "quick-check" as set forth in Attachment III. All quick-check results must be reported to EPA. (Quick-checks will also be performed after every highway fuel economy test run by EPA.) The purpose of this procedure is to verify that the total power absorbed on the dynamometer is equivalent to that expended on the road. The average 55 to 45 mph dynamometer coastdown time, adjusted for differences in equivalent test weight, is compared to the road coastdown specification.

2. The adjustment for differences in ETW is a straight ratio of the ETW classes involved, i.e.:

Mass Adjusted time for comparison to track or target time =

Measured Quick Check Time of Test Vehicle

X

$$\frac{\text{ETW for the target time spec}}{\text{ETW of the test vehicle}}$$

A manufacturer may, as part of its application, submit separate target times for individual ETW categories. These target times can be developed by any appropriate method to account for the reduced rolling resistance of lighter vehicles. If required, mathematical corrections for the measured quick-check time will be to the closest higher ETW specification. For example, if a manufacturer specifies "target" coastdown times at 3750 and 4000 lb. ETW's, a test quick-check time from a 3625 ETW test will be corrected and compared to the 3750 specification.

3. In the event a quick-check fails the confirmation criteria a manufacturer may elect to have a second quick-check performed on the same dynamometer. Results of both quick-checks must be reported: the second time shall be used for confirmation purposes. Alternatively, if the manufacturer determines that the reason the vehicle failed the quick-check was due to a dynamometer equipment problem which would make the quick-check data invalid, the manufacturer may void the emission, fuel economy and quick-check results and run a complete second test sequence on a different dynamometer. While all results must be reported, EPA will only use the second sequence results.

VI. Confirmation Criteria, Corrective Action

A. A production vehicle which does not achieve a 55 to 45 mph road coastdown time equal to or greater than the specification divided by 1.07 is deemed to have failed. A production vehicle which yields a power absorber (DPA) setting greater than 1.10 times the specification is deemed to have failed. Once EPA has test results indicating a failure, the specification is presumed to be inaccurate for the entire population. At that point the manufacturer can revise its specification to reflect the test results or elect to test additional representative production vehicles, subject to EPA oversight and approval. The average of such production vehicle tests, unless the manufacturer can show that it would be inappropriate, would constitute the revised specification. The manufacturer has the burden of establishing correct specifications for any failed population.

B. A mass-adjusted quick-check time which exceeds 1.07 times the specification indicates an inappropriate dynamometer adjustment for that vehicle. A test vehicle which yields a power absorber setting greater than 1.10 times the specification indicates an inappropriate dynamometer adjustment. In either case such a result, by itself, does not call into question the representativeness of the coastdown time. If a test vehicle fails these criteria the manufacturer has several options:

1. Declare that the test vehicle is unrepresentative of the design intent, repair or provide a replacement vehicle, repeat the original tests and provide an engineering report to EPA detailing the reasons why the original tests were unrepresentative.

2. Revise the DPA setting of the group. (Note that this will not affect previous tests unless EPA makes a determination that systematic bias exists, as such tests would have had to pass the quick-check criteria.) All future tests must be run with the new DPA. At the manufacturer's option, the previous tests can be discarded or reassigned the new DPA setting. If it is shown to be more appropriate, the manufacturer may also split the original group into two, leaving some vehicles under the old DPA setting.

3. The manufacturer may determine that the original determination of the road-load of its production vehicles was incorrect and revise the coastdown time.

C. These confirmation tolerances are intended to cover test and vehicle variability as well as differences between vehicles in a population. They do not constitute an allowance. If a sufficient number of representative vehicles are tested, the averages should be very close to the specifications.

D. A systematic bias under any of the confirmation procedures indicates that the specifications are inaccurate and must be corrected.

E. Any revision to the specifications must be used for all subsequent testing. In addition, if the coastdown time specification is revised for any reason, all data previously run for the same model year must be reevaluated for representativeness. If a previous test vehicle fails the quick-check criteria when compared to the corrected coastdown time, that data is void. (Note that any change in DPA setting associated only with a revised coastdown time is immaterial. If the original test results still pass the quick-check criteria when compared to the corrected coastdown time, and no systematic bias exists, EPA will allow the manufacturer to assign the new DPA setting to the original test results.)

F. All data voided under paragraph E, above, must be discarded or replaced for use in CAFE calculations. If any of the data voided was used in a fuel economy label calculation, then, under the provisions of 40 CFR Part 600.312-86(a)(5), we will request that the manufacturer replace the voided data with representative tests (i.e., tests which pass the quick-check criteria when compared with the corrected coastdown time) and recalculate the fuel economy label values. The original sales forecasts should not be revised for this calculation, the only modifications being those necessary to account for the DPA revision. If any of the label values change, the label must be revised. (See Section 600.312-86(a)(6).)

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Attachments

Attachment I

EPA Recommended Practice for Determination of Vehicle Road Force

This procedure characterizes the amount of force necessary to propel a vehicle on a straight and level road. This force is then duplicated on a chassis dynamometer used for emission and fuel economy testing. This specific procedure is optional. A vehicle manufacturer may employ other procedures which yield accurate dynamometer adjustments. In lieu of establishing individual dynamometer settings, the empirical dynamometer adjustment formulas found in the EPA regulations must be employed.

Road force is characterized by means of a "coastdown" technique. The vehicle is allowed to freely decelerate with the transmission in neutral while speed is measured as a function of time. A two-term equation is fitted to the data employing constant and velocity squared terms. The constant term is attributed to tire rolling resistance, the velocity squared term is assured to represent aerodynamic drag. Corrections to standard ambient conditions are made.

A dynamometer coastdown time interval is calculated from the corrected coefficients by adjusting for any differences between the simulated inertia of the dynamometer and the vehicle inertia during the coastdown. The dynamometer power absorption is then determined by adjusting one dynamometer to produce the desired deceleration of the vehicle on that dynamometer. This dynamometer adjustment may then be used to simulate the vehicle road-load on other dynamometers of the same type and roll configuration.

The concept of this coastdown procedure is to adjust the dynamometer so that the vehicle exhibits the same coastdown performance on the dynamometer as on a road or track when the standard ambient conditions prevail.

The attached procedure discusses the facilities, instrumentation, and procedure which satisfy and illustrate the test requirements in detail.

Test Procedure

I. Road or Track Test Facility

The test road or test track should be straight, smooth, and level for a sufficient distance to obtain the necessary data. The necessary distance will vary depending on the vehicle type, the test surface grade, and the ambient conditions; however, the anticipated minimum necessary road or track length is 0.5 to 1 mile (1 to 2 km).

Attachment II

EPA Recommended Practice for Dynamometer Adjustment

This procedure describes the method for determining the dynamometer power adjustment at 50 mi/hr which is appropriate to simulate the road experience of the vehicle. This dynamometer power absorption may then be used to adjust other dynamometers of the same roll size and roll spacing.

If the dynamometer power absorption value is to be submitted to the EPA as part of the request for an alternative dynamometer power absorber setting, the submitted dynamometer power absorption value must be for the 8.65-inch-twin-roll dynamometers with approximately 17 inch roll spacing which are currently used by the EPA. This does not necessarily require that the dynamometer decelerations be performed on such a dynamometer. In general, the roll sizes and spacings of other dynamometers will induce lower tire power dissipation and consequently yield higher dynamometer power absorption adjustments which may be deemed acceptable. The corrected road coastdown time interval is dynamometer invariant and therefore will be used for any confirmatory tests of the acceptability of a requested dynamometer power absorption value.

A. Required Equipment

The only equipment required, other than the vehicle and a properly calibrated dynamometer, is a device to record wheel speed as a function of time for the vehicle-dynamometer coastdowns. The speed-time recording instrumentation shall have an error of $\pm$ 0.01 seconds or less, and the speed error shall be less than 0.2 mph (0.3 km/hr). In the case of dynamometers with multiple rolls contacting the vehicle tire, the speed shall be determined from that roll which is coupled to the dynamometer power absorber.

B. Test Procedure

The procedure simply requires that the vehicle be placed on the dynamometer, the dynamometer and vehicle warmed up, and then the time required for the vehicle to decelerate through a known speed interval be recorded. The following steps delineate this procedure in greater detail.

1. Initial Vehicle-Dynamometer Conditions

    a. The tire pressures should be adjusted to the tire pressures used for the EPA emission certification and fuel economy measurement tests.

Alternatively, if the effective mass of the drive wheel assemblies is not known, it may be estimated as 1.5 percent of the vehicle test mass. In this case, the effective mass of the vehicle-dynamometer system is:

$$M_D = M_I + 0.015M_g \tag{17}$$

When the vehicle is on the dynamometer, the acceleration of the system is given, using equations 9, 15, and 16, as:

$$A = -F^*/M_D \tag{18}$$

or

$$\frac{dv}{dt} = -\frac{(f_0^* + f_2^* v^2)}{M_D}$$

Separating variables and integrating:

$$\Delta T = \frac{M_D}{\sqrt{f^*_0 f^*_2}} [\tan^{-1} \left(\sqrt{\frac{f^*_2}{f^*_0}}\, v_1\right) - \tan^{-1} \left(\sqrt{\frac{f^*_2}{f^*_0}}\, v_2\right) \tag{19}$$

where:

$\Delta T = t_2 - t_1$, the coastdown "target" time interval
v_1 = 55 mph
v_2 = 45 mph.

Care must be taken when using equation 19 to ensure that f^*_2 and f^*_0 are in the appropriate system of units, or conversion factors are provided such that the arguments of the trigonometric functions are dimensionless. Likewise, the result of the equation, ΔT, must have the units of seconds.

b. The vehicle mass shall be adjusted such that the weight of the test vehicle is within 100 pounds of the projected production vehicle weight with 40 percent fuel fill. In addition, the drive axle load shall be within 50 pounds of the design rear axle load of the vehicle.

c. The vehicle should be placed on the dynamometer and secured in the usual fashion; care should be taken not to introduce any downward loading on the vehicle drive axle from the restraining system.

d. The dynamometer should be adjusted to the inertia simulation appropriate for the vehicle.

e. The dynamometer power absorption should be adjusted to the approximate dynamometer power absorption expected for the vehicle.

One deviation from the normal vehicle and dynamometer operation which is permissible is that the dynamometer need not be preconditioned. The required vehicle warm-up is sufficient to provide the necessary dynamometer conditioning.

2. The Vehicle-Dynamometer Warm-Up

A significant aspect of this procedure is warm-up of the vehicle-dynamometer system until quasi-equilibrium conditions are achieved. The vehicle tires are probably the most important element in the system from the warm-up standpoint. The recommended warm-up is to operate the vehicle over two of the EPA HFET driving cycles. The coastdown measurements should be started within one minute of completion of the last HFET cycle.

3. The vehicle should be accelerated at the approximate rate of 2 mi/hr-sec. (3 km/hr-sec.) to at least 60 mph (100 km/hr) and shifted into neutral with the clutch engaged, if applicable. The coastdown should be conducted with the vehicle throttle closed and without application of the vehicle brakes. During the coastdown, the time required for the vehicle-dynamometer system to freely decelerate from 55 mph to 45 mph (88.5 to 72.4 km/hr) shall be recorded. This coastdown shall be repeated until 3 results which differ by no more than 0.30 seconds are obtained.

4. The dynamometer power absorption shall then be changed and step 3 repeated. In this manner coastdown time data shall be obtained for a minimum of five dynamometer power absorption settings. The range of these coastdown times obtained shall include the "target dynamometer coastdown time" which shall be at the approximate midpoint of the observed coastdown times.

C. Data Analysis

The reciprocal of the coastdown time shall be plotted versus the dynamometer power absorption.

A regression line shall be fitted to these data by the method of least squares. The form of the regressions shall be

$$\frac{1}{\Delta t} = b_0 + b_1 P \qquad (20)$$

where:

P = the dynamometer power
Δt = the dynamometer coastdown time interval
b_0 and b_1 are regression coefficients.

The dynamometer power absorption shall then be computed from equation 20 using the "target" dynamometer coastdown time.

Attachment IV

Sample Application

The following sample application is one method of presenting road force and dynamometer specifications. Manufacturers may use any method that clearly expresses the required information. Manufacturers with diverse product lines may require a much more detailed description of the vehicle population.

Attachment III

EPA Recommended Practice for Dynamometer Quick-Checks

This procedure is similar to that for dynamometer adjustment. It is performed after the highway fuel economy test (HFET) and is used to determine the appropriateness of the dynamometer power absorber adjustment.

1. Begin the procedure within one minute of the completion of the HFET.

2. The vehicle should be accelerated at the approximate rate of 2 mi/hr-sec. (3 km/hr-sec.) to at least 60 mph (100 km/hr) and shifted into neutral with the clutch engaged, if applicable. The coastdown should be conducted with the vehicle throttle closed and without application of the vehicle brakes. During the coastdown, the time required for the vehicle-dynamometer system to freely decelerate from 55 mph to 45 mph (88.5 to 72.4 km/hr) shall be recorded. This coastdown shall be repeated until 3 results which differ by no more than 0.30 seconds are obtained.

3. The quick-check time is the average of the three results.

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The road or test track surface should be hard and smooth. The surface texture and composition should be similar to road surfaces commonly in use. Grade shall not exceed 0.5 percent and road crown should be minimal. The grade must be constant, ± 0.1 percent, throughout the test section.

Tests must be conducted on the road or track in both directions with minimal interference from other vehicles during the data collection periods. During the data collection period, the track surface and vehicle should be dry, the track should be free of obstacles or significant irregularities. The absence of intermittent wind barriers near the road or track surface is preferred to reduce positional wind variations.

II. Instrumentation.

The parameters which must be measured are the speed versus time during the vehicle coastdown, the vehicle mass, and the ambient conditions. The following instrumentation is required for these measurements.

A. Vehicle Measurements

1. Vehicle Speed Versus Time

The vehicle speed versus time instrumentation shall have an accuracy of at least 0.2 mi/hr (0.4 km/hr) and resolution of 0.1 mi/hr (0.2 km/hr). The timing error shall be less than 0.1 percent.

2. Vehicle Mass

The scale used to determine the vehicle mass shall be accurate to within ± 20 lbs (10 kg).

B. Ambient Condition Instrumentation

1. Wind Speed and Direction

The wind speed instrumentation should be accurate to ± 2 mi/hr (3 km/hr), and should be able to measure the velocity of wind gusts of 5 sec. duration to this accuracy. The wind direction instrument should have an accuracy of ± 0.2 radians (11.5°).

2. Temperature

The temperature instrument shall have an accuracy of ± 2°F (± 1°C).

3. Barometric Pressure

The barometric pressure instrument shall be a quality meteorological instrument with an accuracy of at least 0.2 in. Hg (0.3 kPa).

III. Vehicle Preparation

A. The test vehicle should be in the condition and adjustment recommended by the manufacturer for normal operations. As the purpose of this procedure is to characterize the performance of actual production vehicles, the test vehicle shall not receive any preparation which would make it unrepresentative of production. The vehicle should be broken in with sufficient mileage so that drive train friction is stabilized. The following items in particular, shall comply with the manufacturer's recommended specifications.

1. Tire pressure (if more than one inflation pressure is recommended, the minimum pressure recommended by the manufacturer shall be used). This pressure shall be adjusted with the tires at the test ambient temperature.

2. Tires, wheels, and wheel covers.

3. Wheel alignment.

4. Brake adjustment.

5. Lubricants in the drive train and in the wheel bearings.

6. Vehicle suspension height and attitude.

B. The tires used on the vehicle must be broken in for at least 60 miles (100 km). This break-in should be done at the manufacturer's recommended tire pressure and specified wheel alignment. The break-in should be done on the test vehicle, or on a similar vehicle. The vehicle tires must have at least 50 percent of the original usable tread depth remaining.

C. The vehicle mass shall be adjusted such that the weight of the test vehicle, including instrumentation and any on-board observing personnel, but excluding the driver, is within 100 pounds of the projected production vehicle weight with 40 percent fuel fill. In addition, drive axle load shall be within 50 pounds of the design drive axle load of the vehicle.

IV. Ambient Conditions

A. Standard Ambient Conditions

Since the ambient conditions will affect the vehicle road load, standard ambient conditions are chosen to be:

1. Wind - Still air, zero wind speed;

2. Temperature - 68°F (20°C);

3. Barometric pressure - 29.0 in. Hg at 60°F (98 kPa).

B. Test Ambient Conditions

1. Wind

Steady winds should be less than 10 mi/hr (16 km/hr) and peak wind speed shall not exceed 15 mi/hr (24 km/hr). The data analysis only treats steady winds in the direction of the vehicle travel. Consequently, if any wind is present, a steady wind in the direction of the test road or track is the preferred condition.

2. Temperature

The ambient temperature at the test time shall be in the range 41°F (5°C) to 95°F (35°C).

3. Barometric Pressure

The barometric pressure shall be in the range of 31 in. Hg (104 kPa) to 27 in. Hg (91 kPa).

V. Procedure

A. Speed Versus Time Measurements

1. Warm-Up

Prior to collection of the speed-time data, the vehicle shall be warmed up thoroughly at a steady speed of approximately 50 mi/hr (80 km/hr). The warm-up period shall be sufficient to allow all tire and lubricant temperatures to essentially reach their equilibrium value. A warm-up period of 30 minutes is considered sufficient for most light-duty vehicles.

2. Vehicle Coastdowns

The vehicle must be accelerated to some speed greater than the intended initial coastdown data speed (approximately 65 mi/hr), the transmission shifted into neutral with the clutch engaged, if applicable, and several seconds allowed to elapse for the vehicle drive train to stabilize. After the short stabilization period, the speed versus time data are collected for the freely decelerating vehicle.

The standard speed for adjusting the dynamometer power absorber has been chosen as 50 mi/hr (80.5 km/hr). The speed-time coastdown data must include this speed if it can be attained by the vehicle. The recommended coastdown speed range is 60 mi/hr (100 km/hr) to 20 mi/hr (30 km/hr).

The coastdown process shall be repeated, in alternate directions, for a minimum of 5 paired runs. A paired run is a coastdown in one direction directly followed by a coastdown in the alternate direction.

B. Ambient Measurements

The ambient data shall be monitored during the time required to complete the coastdowns.

1. Wind

The wind speed and wind direction instrumentation shall be located within 1 mi (2 km) of the test track or road near the center of the test section, at approximately the same altitude as the geometric center of the vehicle.

2. Temperature

The temperature instrument shall be located within 1 mi (2 km) of the test track or road, and preferably as close as possible. The temperature instrumentation should measure air temperature and hence be shielded from the sun or other radiant energy sources.

3. Barometric Pressure

The measured barometric pressure shall be station pressure, not corrected to sea level. It is preferable to have the instrumentation within 1 mi (2 km) of the test road or track.

C. Vehicle Inertia

1. Mass

The mass of the vehicle including the driver, the test instrumentation, any ballast, and any observers carried at the time of the coastdown testing must be determined. The test mass shall be determined by weighing the vehicle immediately after completion of the coastdown test.

2. Rotational Inertia

The equivalent effective mass of the tire-wheel-brake assemblies must be known. If the inertia of a wheel assembly is experimentally measured or calculated from the inertias of the components, the equivalent effective mass of this assembly is given by:

$$M_e = I/R^2 \tag{1}$$

where:

M_e = the equivalent effective mass of a single wheel and tire

I = the rotational inertia of the assembly

R = the rolling radius of the tire.

The total effective mass of vehicle is then given by:

$$M = M_g + 4M_e \qquad (2)$$

where:

M = the total effective mass of the vehicle
M_g = the gravitational mass of the vehicle as tested

Alternatively, if the rotational inertia of the tire-wheel assemblies is not known, the effective mass of the four tire-wheel assemblies and drive train components may be estimated as 3.0 percent of the vehicle test mass. In this case the total effective mass of the vehicle system is:

$$M = 1.030\ M_g \qquad (3)$$

VI. Data Analysis

A. The Road Force

The main task which must be accomplished in the data analysis is the extraction of the acceleration versus velocity information from the speed versus time data. The approach used is to assume a model form of the acceleration versus speed equation and then perform analytical operations on this equation to convert it to the form of a speed versus time function. The expression may then be directly fitted to the velocity versus time data. With this approach, a polynomial expression for the acceleration as a function of velocity must first be constructed.

Under ideal wind-free conditions the acceleration, A, is assumed to have the form:

$$A = -(a_0 + a_2 v^2) \qquad (4)$$

The a_2 term (equation 4) is identified as the aerodynamic term and the velocity in this equation must be the vehicle air speed. Therefore, if any ambient wind exists, equation 4 must be written as:

$$A = -[a_0 + a_2(v - \underset{\sim}{s} \cdot \underset{\sim}{w})^2] \qquad (5)$$

where:

$\underset{\sim}{s}$ = a unit vector in the direction of vehicle travel

$\underset{\sim}{w}$ = the wind velocity vector.

It should be noted that this analyses only considers the effect of the component of wind in the direction of vehicle travel.

A term must be added to equation 5 to describe the effects of any grade. The grade term is equal to $g\sin\delta$ where δ is the angle between the test surface and the horizontal and g is the acceleration due to gravity. Since δ is a very small angle, the approximation of using the grade, δ (in radians), for $\sin\delta$ is quite accurate. Inserting this grade term, equation 5 becomes:

$$A = -[a_0 + g(\underset{\sim}{\delta}\cdot\underset{\sim}{s}) + a_2(v - \underset{\sim}{s}\cdot\underset{\sim}{w})^2] \qquad (6)$$

where:

$\underset{\sim}{\delta}$ = a vector in the track direction of increasing grade with a magnitude equal to the track or road grade.

In equations 5 and 6, the signs of the vectors $\underset{\sim}{\delta}$, $\underset{\sim}{w}$, and $\underset{\sim}{s}$ must be chosen so that vehicle motion in the uphill direction and when encountering a headwind results in an increase in the rate of the vehicle deceleration.

Expanding and regrouping, equation 6 becomes:

$$\frac{dv}{dt} = -\left\{[a_0 + a_2(\underset{\sim}{w}\cdot\underset{\sim}{s})^2 + g(\underset{\sim}{\delta}\cdot\underset{\sim}{s})] - 2a_2(\underset{\sim}{w}\cdot\underset{\sim}{s})\, v + a_2 v^2\right\} \qquad (7)$$

where, in addition, the acceleration has been written as the time derivative of the velocity.

The variables of equation 7 may be separated and integrated in closed form. The resulting functions may then be inverted to yield expressions for the vehicle velocity as a function of time. The resulting expression for the velocity during the coastdown as a function of time is:

$$v = (B/a_2)\tan[B(C-t)] + (\underset{\sim}{w}\cdot\underset{\sim}{s}) \qquad (8)$$

where:

$B^2 = a_2[a_0 + g(\underset{\sim}{\delta}\cdot\underset{\sim}{s})]$

C = the constant of integration, dependent on the initial conditions

$$= \frac{1}{B}\tan^{-1}\left[\frac{a_2 v_0 - a_2(\underset{\sim}{w}\cdot\underset{\sim}{s})}{B}\right]$$

V_0 = the initial velocity

Equation 8 is only appropriate under the condition $B^2 > 0$. This should be assured by the conditions imposed on the track grade, however, care should be taken to ensure this is the actual case.

Equation 8 must be fitted to the coastdown data to obtain the desired coefficients a_0 and a_2. This fitting process must be done by one of the generalized least squares methods. The recommended approach is to fit all coastdown runs simultaneously allowing $\underset{\sim}{w}$ to also be a fitted parameter. This conveniently accomplishes the directional averaging of the runs and removes any constant or velocity dependent directional effects.

The total road-load force is now calculated from the acceleration coefficients by Newton's second law:

$$F = MA \tag{9}$$

that is:

$$F = M\,(a_0 + a_2 v^2)$$

where F is the total road force.

The road force may be expressed in terms of force coefficients:

$$F = f_0 + f_2 v^2 \tag{10}$$

where:

$$f_0 = Ma_0$$

$$f_2 = Ma_2$$

B. Ambient Correction to the Total Road Force

The total road-load must be corrected to the standard ambient conditions. Since the f_2 coefficient is assumed to be the aerodynamic drag component, this term is corrected for differences between the air density under test conditions and and the air density at the standard conditions. The corrections can be written in the form:

$$f_2{*} = C^T \times C^B \times f_2 \tag{11}$$

where:

$f_2{*}$ = the corrected force coefficient for the v^2 term

C^T = the temperature correction factor for the ambient conditions

$$= (459.7° + T)/527.7° \tag{12}$$

where T is the test ambient temperature in degrees F.

C^B = the barometric correction factor for the ambient conditions.

$$= 29.0\ Hg/BAR \tag{13}$$

where BAR is the test ambient barometric pressure in inches Hg.

The constant term f_0 is assumed to represent the tire rolling resistance and should be corrected for the difference between the test ambient temperature and the standard ambient temperature. The correction may be expressed as:

$$f_0^* = f_0[1 + K_0(T - 68°F)] \tag{14}$$

where K_0 may be assumed to be $4.8 \times 10^{-3}/°F$, unless a different value is specified by the manufacturer.

The force on the vehicle at the standard ambient condition is, therefore, given from the above terms as:

$$F^* = f_0^* + f_2^* v^2 \tag{15}$$

C. The Dynamometer Coastdown Time

The intent is to ensure duplication of the total road force, at standard ambient conditions, on the dynamometer. The method used to accomplish this is to compute a "target coastdown time" for the dynamometer and then adjust the dynamometer until this coastdown time is obtained. This section discusses the calculation of the target dynamometer coastdown time.

The force which should act on the vehicle system is given by equation 15. The effective mass of the vehicle and dynamometer system is:

$$M_D = M_I + 2M_e \tag{16}$$

where:

M_D = the total effective mass of the vehicle-dynamometer system

M_I = the equivalent mass simulated by the dynamometer flywheels

M_e = the effective equivalent mass of one drive wheel and tire.

ROAD FORCE AND DYNAMOMETER SETTING SPECIFICATIONS

Vehicle Model	Tires	Trans	Test Weight	W/O AC FACTOR CD Time	W/O AC FACTOR Test HP	W/AC FACTOR CD Time	W/AC FACTOR Test HP	Notes
Able Wagon	all 13"	Man	0-3125	17.77	6.4	16.82	7.0	Coastdown
Able Sedan	" "	Auto	0-3125	17.00	6.4	16.16	7.0	Calculated
(Note 1)	P215/60R14	Auto	3250	15.72	5.4	14.95	5.9	Calculated
Baker Sedan	P195/75R14	Auto	0-3500	20.29	6.6	19.14	7.3	Coastdown
Baker Wagon	P205/70R14	Auto	0-3500	20.29	6.6	19.14	7.3	Calculated
Charlie Sedan	P245/50R16	Auto	3750	17.35	7.4	16.39	8.1	Calculated
Charlie Wagon (Note 2)	P205/70R14	Auto	0-3625	19.23	7.0	18.07	7.7	Wind tunnel
Truck - 2WD	Radial	All	0-5000	14.18	16.2	13.30	17.6	Coastdown
	Bias	All	0-5000	12.77	18.0	12.04	19.4	Coastdown
	Mud	All	0-5000		23.0		24.4	Frontal Area

NOTES

The wind tunnel method is described in a letter to R. E. Maxwell dated January 15, 1984.

"Calculated" values are derived as described in letter to R. E. Maxwell dated July 19, 1985, based on coastdown or wind tunnel values, adjusted for tire, transmission and other changes.

(1) Able sedan has slightly lower road-load, is optionally included in Wagon population.

(2) Charlie Wagon has roof rack and air deflector is over 33 percent option, and cannot be grouped with the similar Baker Wagon.